Direct-photon+hadron correlations to study parton energy loss with the STAR experiment

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U.S. DEPARTMENT OF ENERGY

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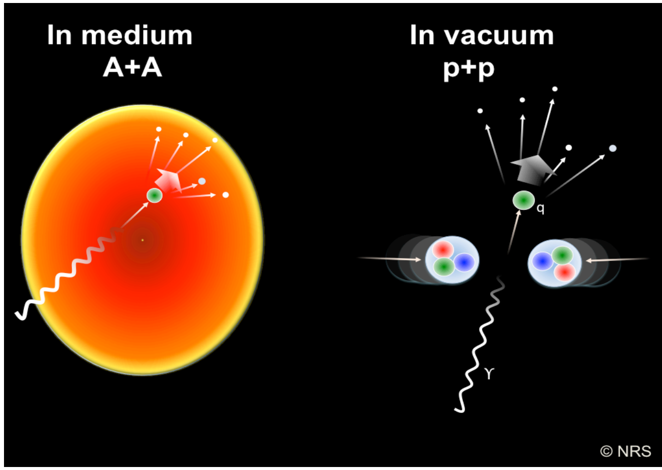
Motivation: *Direct photon and its advantage*

- **Compton scattering (qg->qγ) dominates for the direct photon production**
- **It doesn't interact strongly in medium**
  - *Transverse energy approximates that of initial parton p_T in photon-jet events*
- **A good tomographic probe of the quark-gluon plasma in high-energy heavy-ion collisions**



- *Volume emission dominates for dir. photon trigger hadron correlation unlike di-hadron correlation*

Zhang et al.,PRL 103, 032302 (2009)

- **Parton energy loss in medium depends on**
  - *Initial energy (E), Path length (L), Color factor (C_R), coupling strength (α_s), transport coefficient ($\hat{q}$)etc.*
    - **Initial energy**: **γ_{dir}-h$^{\pm}$ correlation at different p_T^{trig}**
    - **Path length** or ***Color* factor : comparison between γ_{dir}-h$^{\pm}$ and π^0-h$^{\pm}$ correlation**
      (Away-side hadrons of γ_{dir} triggered should suppress less compared with that of π^0)

Medium Effect: *Direct photon-hadron and Di-hadron correlation*

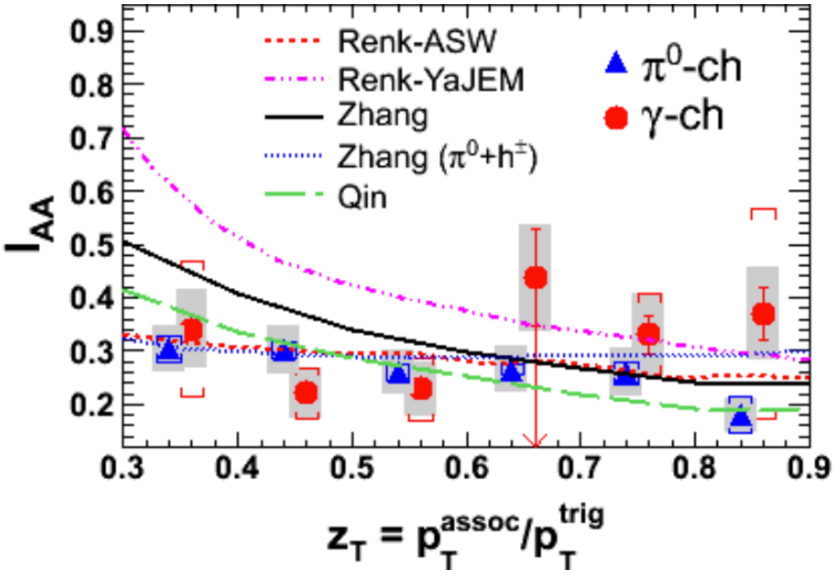
- The medium effect *for Υ_{dir}*-hadron and π^0-hadron by,

Nuclear modification factor:

$$I_{AA} = \frac{D(z_T)_{AA}}{D(z_T)_{pp}}$$

$D(z_T)_{AA}$: per trigger away-side yield for A+A collisions
$D(z_T)_{pp}$: per trigger away-side yield for p+p collisions

$8 < p_T^{trig} < 16$ GeV/c, $0.3 < z_T < 0.9$



(STAR Collab., PRC 82, 034909)

Key questions on

- What about lost energy ?
- redistribution in medium or recovery at low z_T ?

Beside, small z_T dominated by volume emission

Zhang et al.,PRL 103, 032302 (2009)

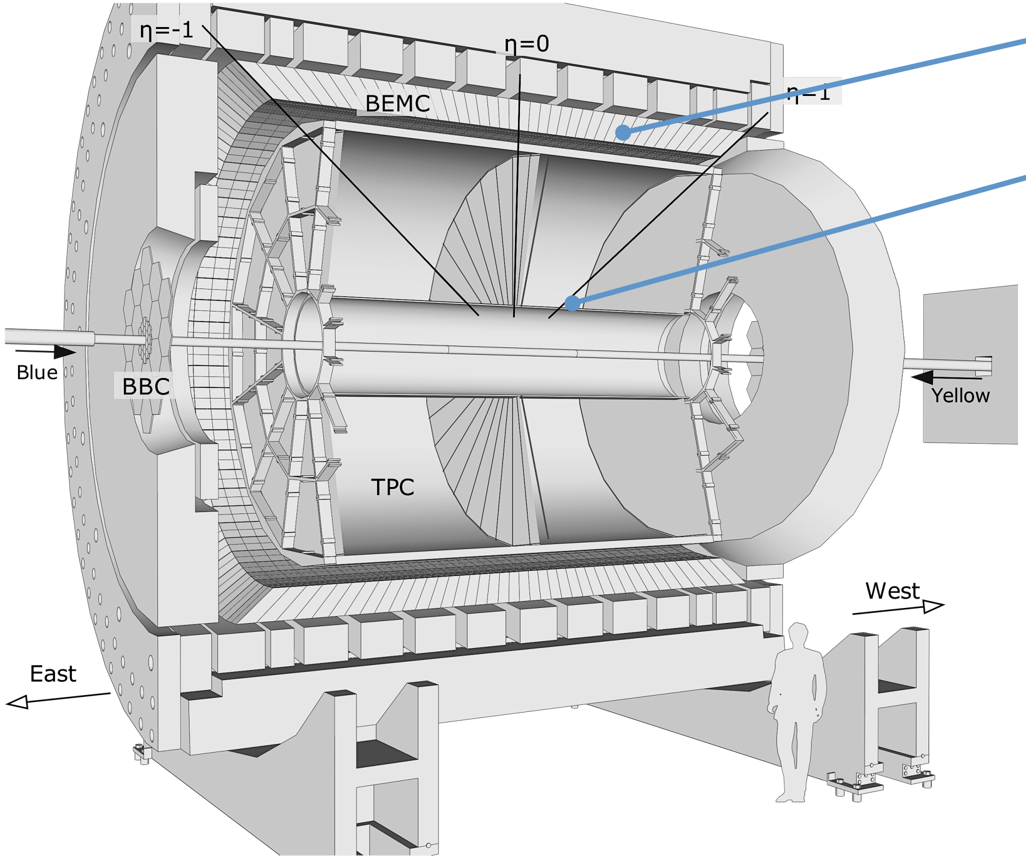
To understand medium effect at low z_T

triggered by high p_T Υ_{dir} and π^0 ***:$12 < p_T^{trig} < 20$ GeV/c***

low p_T associated hadron: ***$p_T^{assoc} > 1.2$ GeV/c***

This presentation

STAR detector system: *Advantage and data sets*

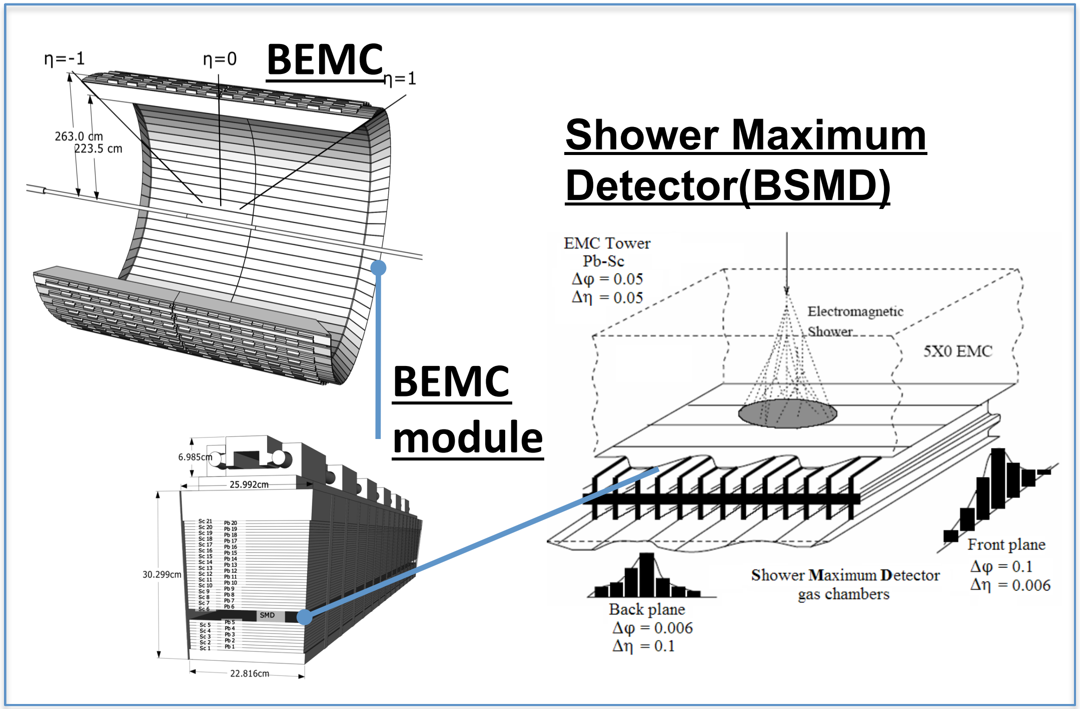


- **Barrel ElectroMagnetic Calorimeter (BEMC) to identify EM clusters**
- **Time Projection Chamber (TPC) for identifying charged hadron tracks**
- **STAR detector system gives unique opportunity full 2π-azimuth and wide $|\eta| < 1.0$, both for BEMC and TPC**
- **Triggered on high energy tower in the BEMC**

- **Au+Au 200 GeV**
  (year-11: Int. Luminosity of 2.8 nb^{-1})
- **p+p 200 GeV**
  (year-9: Int. Luminosity of 23 pb^{-1})

- ***Discrimination between $\pi^0 \rightarrow \gamma\gamma$ and γ_{dir} is key part of this analysis***
  - **By Transverse Shower Profile (TSP) method**
  - **Using Barrel shower Maximum detector (BSMD)**

Transverse shower profile: *π^0/Υ_{dir} discrimination*



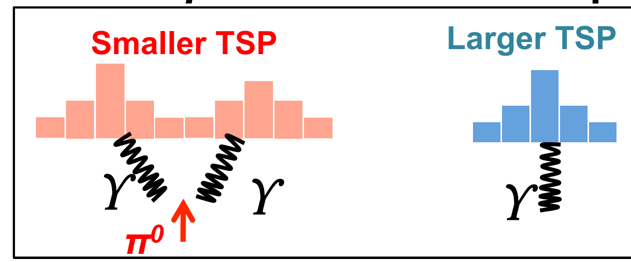
- BSMD η-trips and ϕ-strips along with BEMC tower give information about Transverse Shower Profile (TSP)

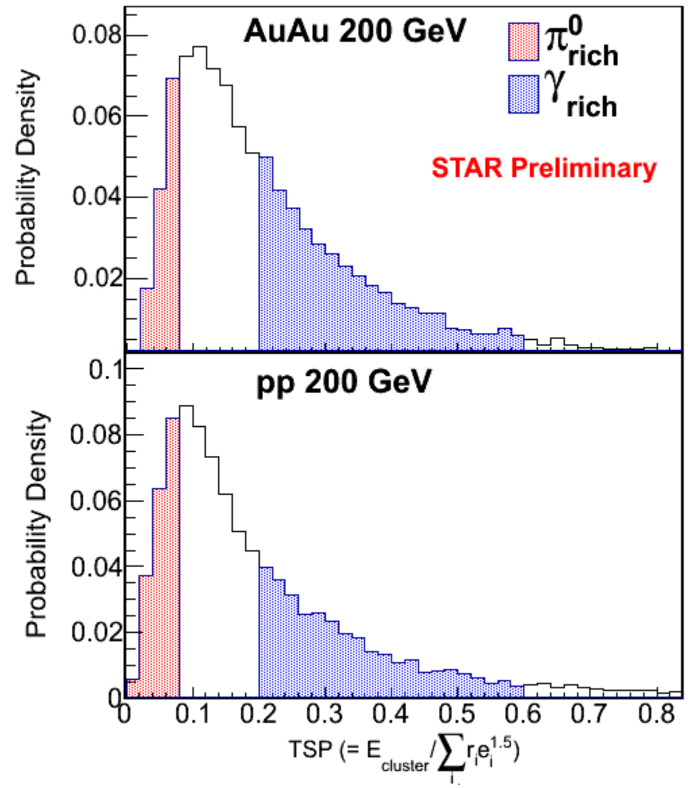
$$\mathrm{TSP} = \frac{\mathrm{E_{cluster}}}{\sum_i \mathrm{e_i r_i^{1.5}}}$$

$E_{cluster}$: Cluster energy, e_i: BSMD strip energy, r_i: distance of the strip from the center of the cluster

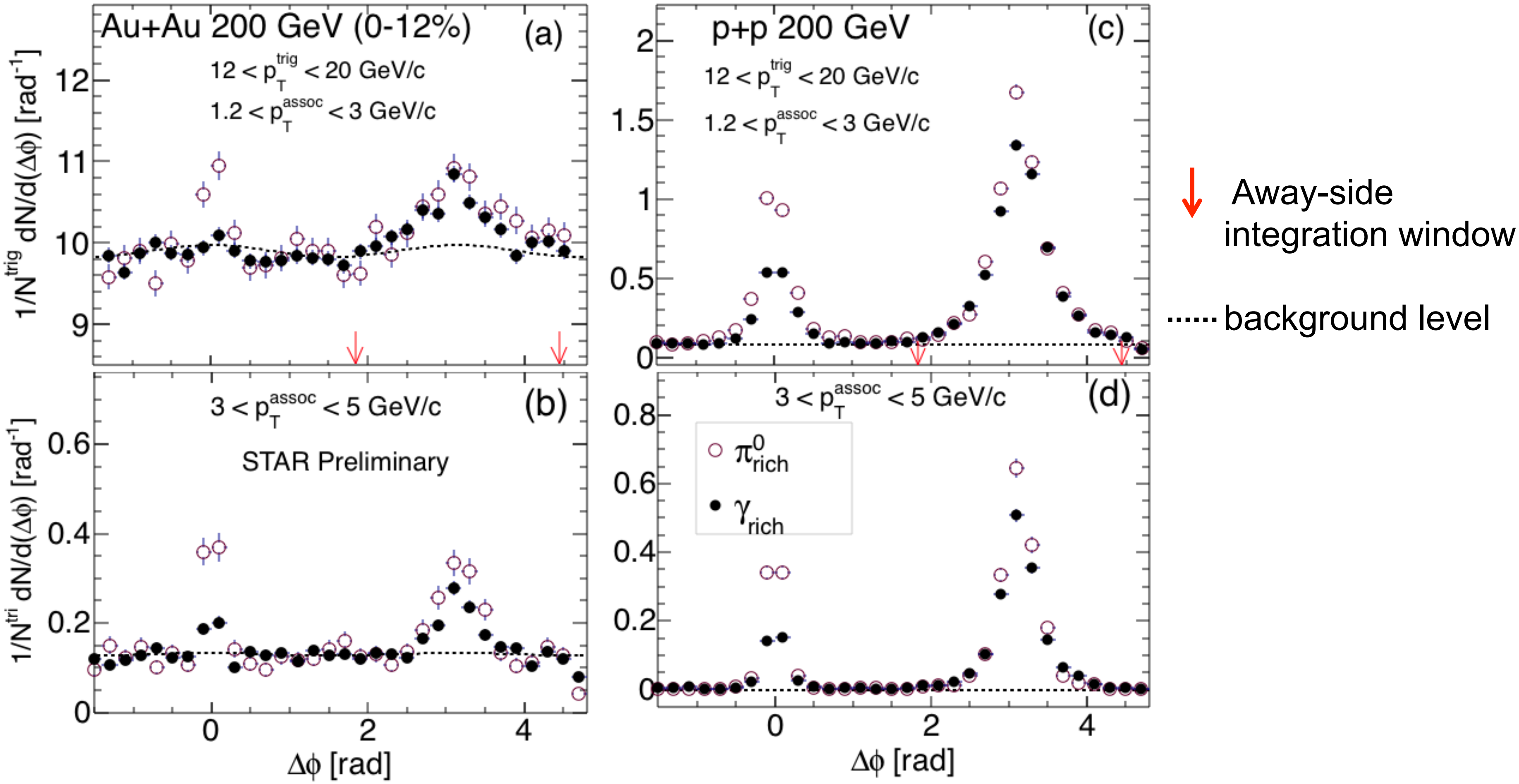
- Wider shower represents small TSP and vise versa
- TSP cuts are tuned to get
  - a nearly pure sample of π^0 (called " π^0_{rich} ")
  - a sample with enhanced fraction of Υ_{dir} (called ` Υ_{rich} ')

π^0 sample **Photon sample**



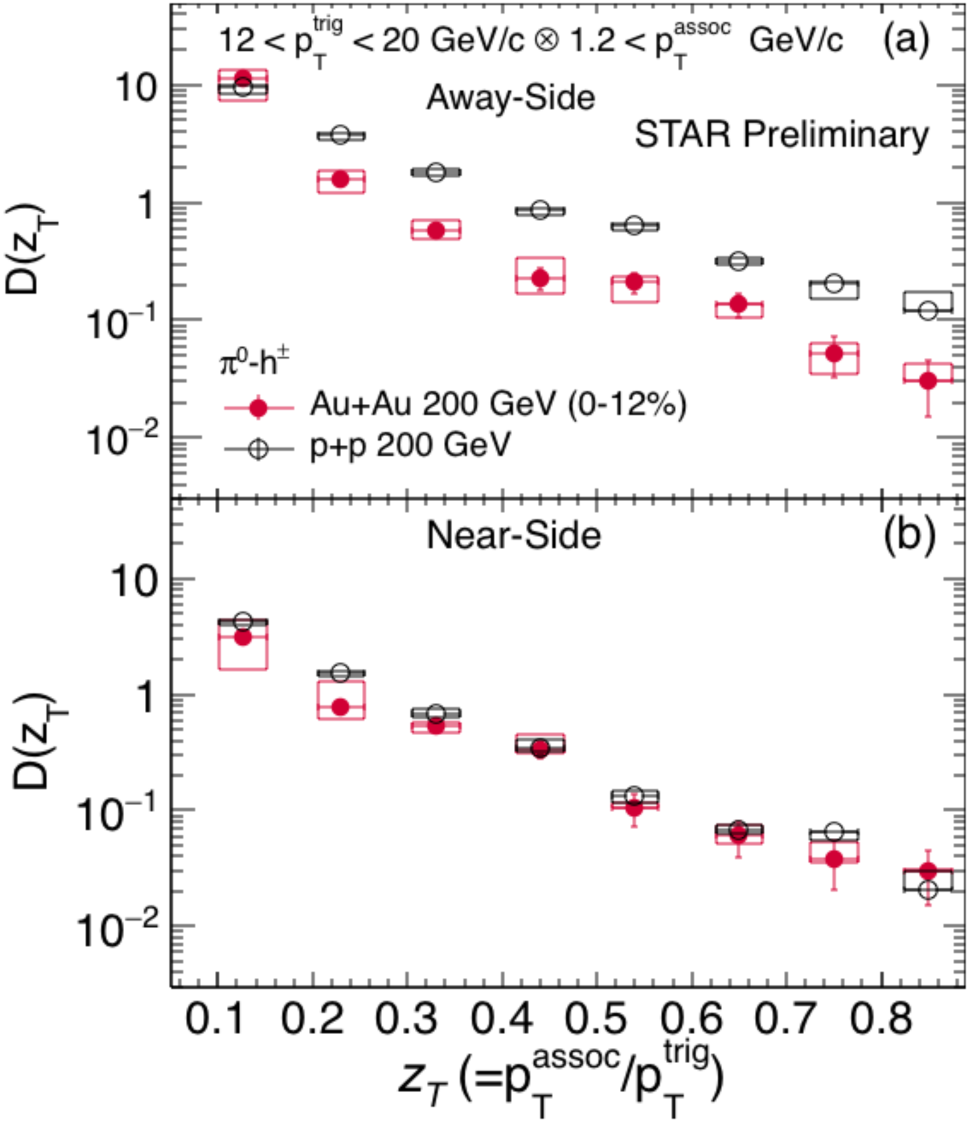


Correlation functions



- Raw correlation functions for π^0_{rich} and γ_{rich} triggered associated hadrons in $|\eta| < 1.0$
- Uncorrelated background is then subtracted and $\Delta\phi$ acceptance is corrected using the mixed events (modulated with elliptic flow for Au+Au collisions)

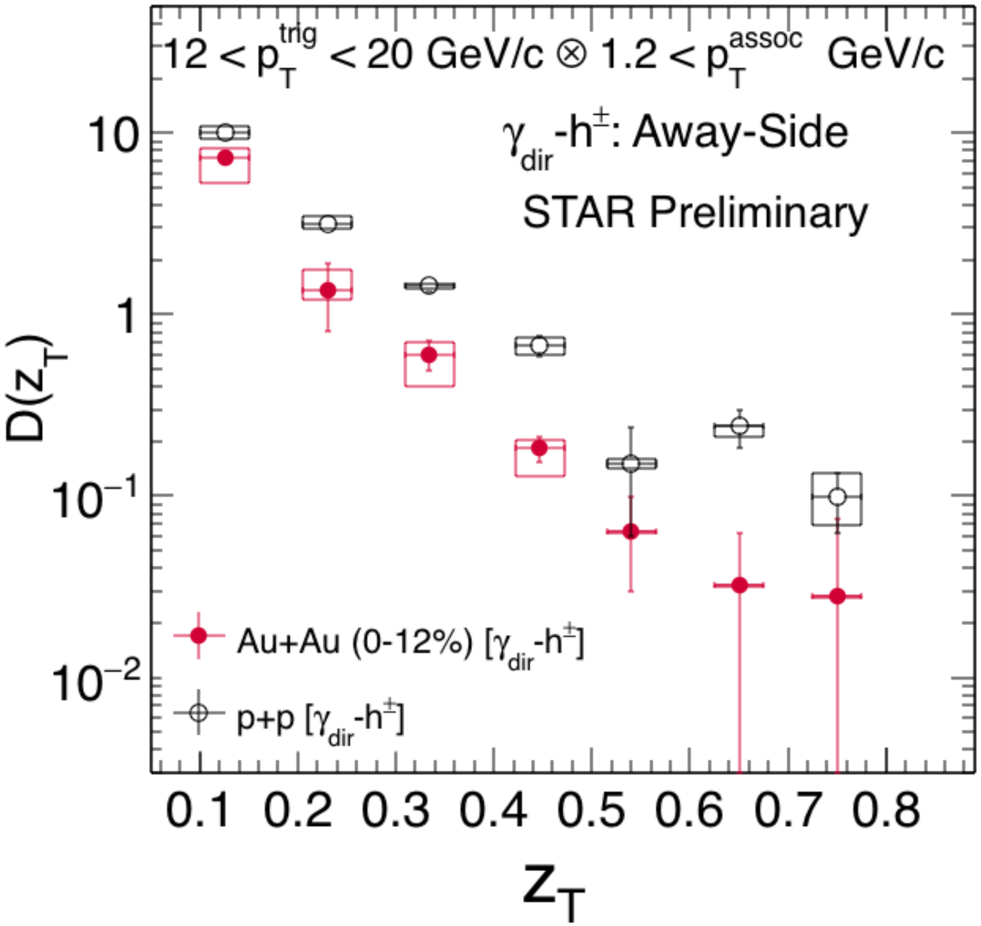
Yields associated with π^0 - trigger



- Near-side and away-side yields are extracted within $|\Delta\phi| \le 1.4$ and $|\Delta\phi - \pi| \le 1.4$
- AuAu central (0-12%) collisions compare with pp collisions at 200 GeV colliding energy
- **Away-side yields show suppression in AuAu collisions as compared with pp collisions**
- **Near-side shows no significant suppression**
- **By integrating near-side yields, we estimated 85(±3)% fraction of energy carried by π^0 over "jet energy" (π^0 + charged hadrons) in pp 200 GeV**

Yields associated with γ_{dir} – trigger: *Fragmentation function*

Away-side yields are extracted within |Δϕ – π| ≤ 1.4



$$Y_{\gamma_{dir}+h} = \frac{Y^{a}_{\gamma_{rich}+h} - RY^{a}_{\pi^0+h}}{1-R}$$

$Y^{a(n)}_{\gamma_{rich}+h}$ and $Y^{a(n)}_{\pi^0+h}$: away-side (near-side) yields of associated particles per γ_{rich} and π^0 trigger, respectively.

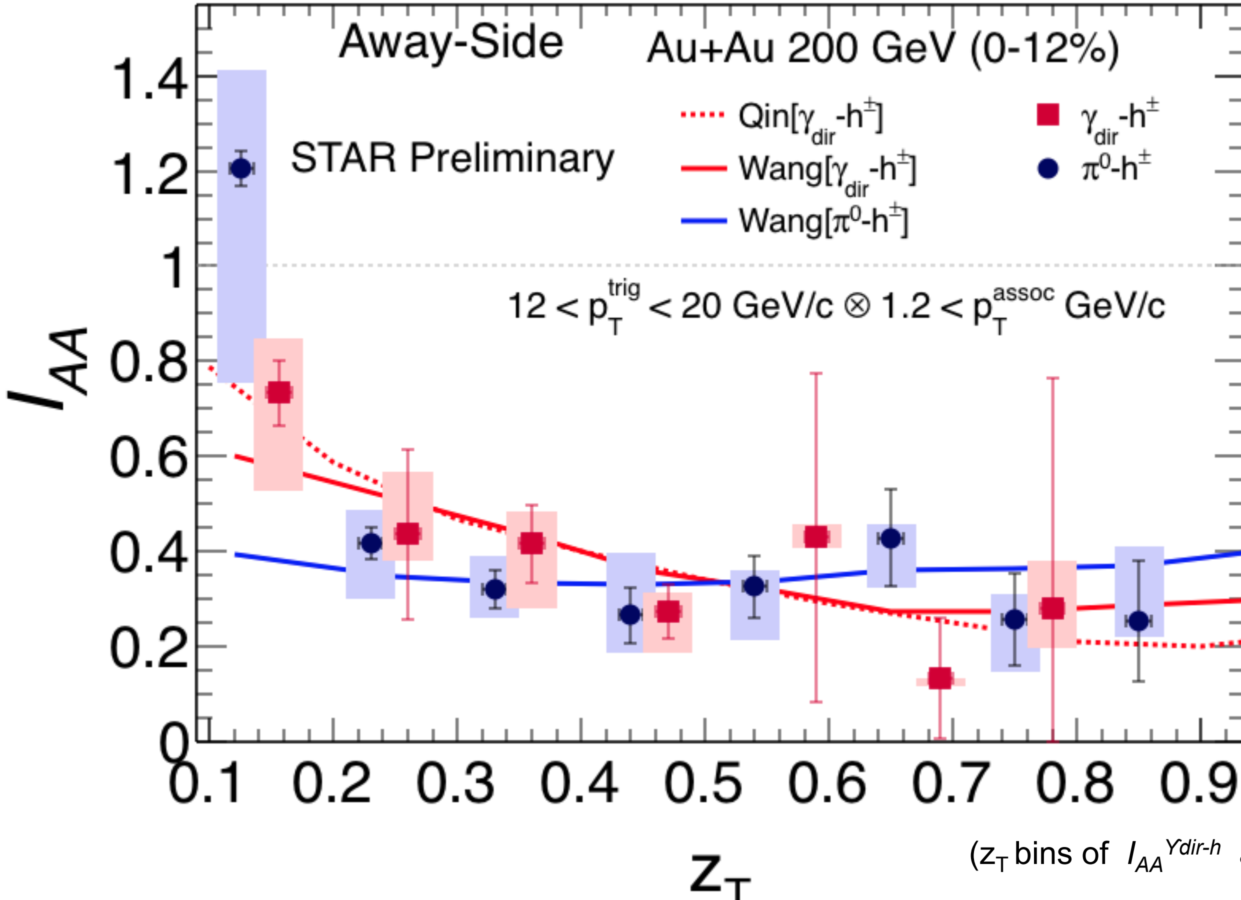
Purity of dir. Photon over photon rich sample

$$1 - R = \frac{N_{\gamma^{dir}}}{N_{\gamma^{rich}}}$$

($1-\mathcal{R}$) are ~40% and ~70% for p+p and Au+Au central (0-12%) collisions, respectively

- **Away-side yields show suppression in Au+Au collisions as compared with p+p**

Nuclear modification factor: I_{AA} of γ_{dir} and π^0



Qin:
G.-Y Qin et al.,PRC 80, 054909 (2009)
(NLO pQCD + (3+1)hydro with jet-medium and fragmentation photon)

Wang:
X. N. Wang et al.,
Phys. Rev. C 84, 034902 (2011)
Phys. Rev. C 81, 064908 (2010)
Phys. Rev. Lett. 103, 032302 (2009)
(NLO pQCD + (3+1)hydro)

$$I_{AA} = \frac{D(z_T)_{AA}}{D(z_T)_{pp}}$$

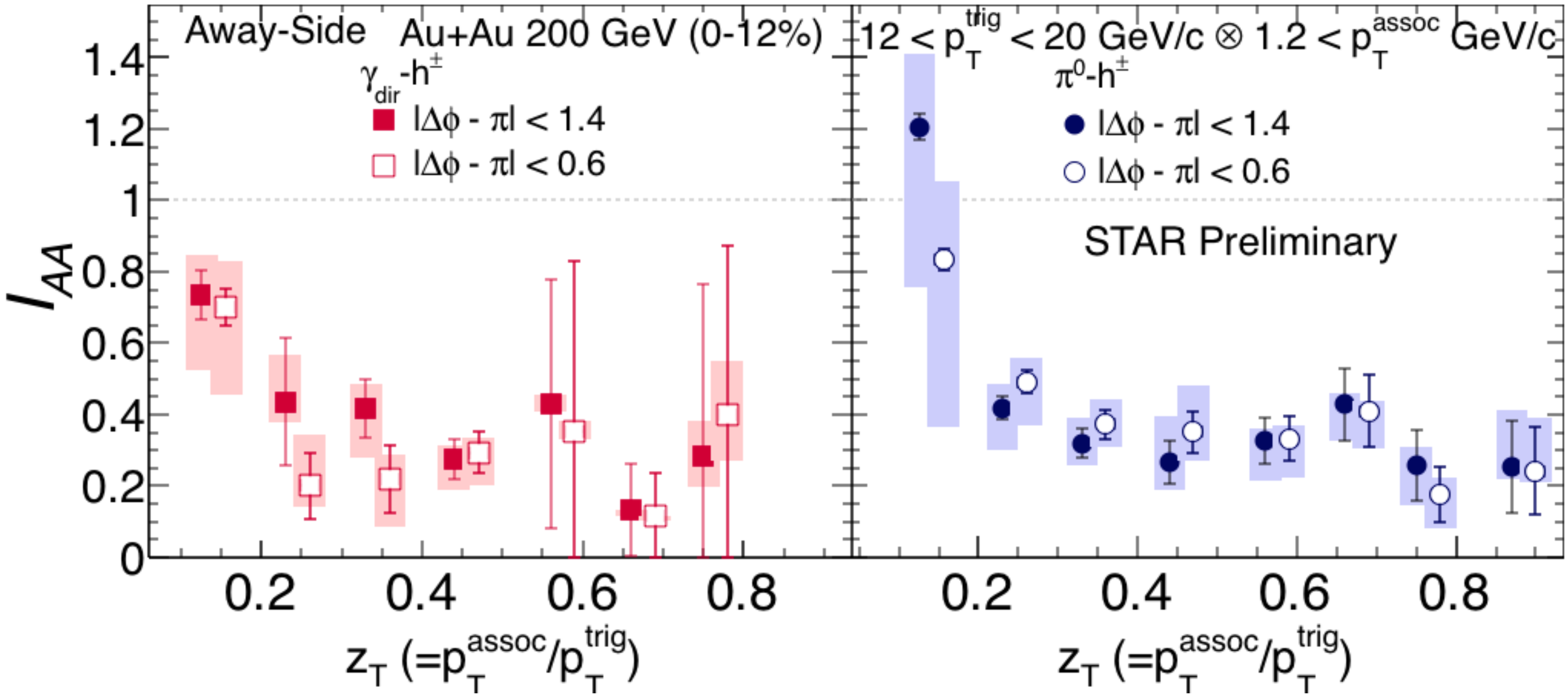
$$z_T = \frac{p_T^{assoc}}{p_T^{trig}}$$

(z_T bins of $I_{AA}^{\gamma dir\text{-}h}$ *are shifted by 0.03 unit for visibility)*

- $I_{AA}^{\pi 0\text{-}h}$ **and** $I_{AA}^{\gamma dir\text{-}h}$ **show similar and strong suppression**
- **At very low z_T ($0.1 < z_T < 0.2$), both** $I_{AA}^{\pi 0\text{-}h}$ **and** $I_{AA}^{\gamma dir\text{-}h}$ **show less suppression than at high z_T**
- **Models don't include absorption and redistribution of lost energy in the medium**

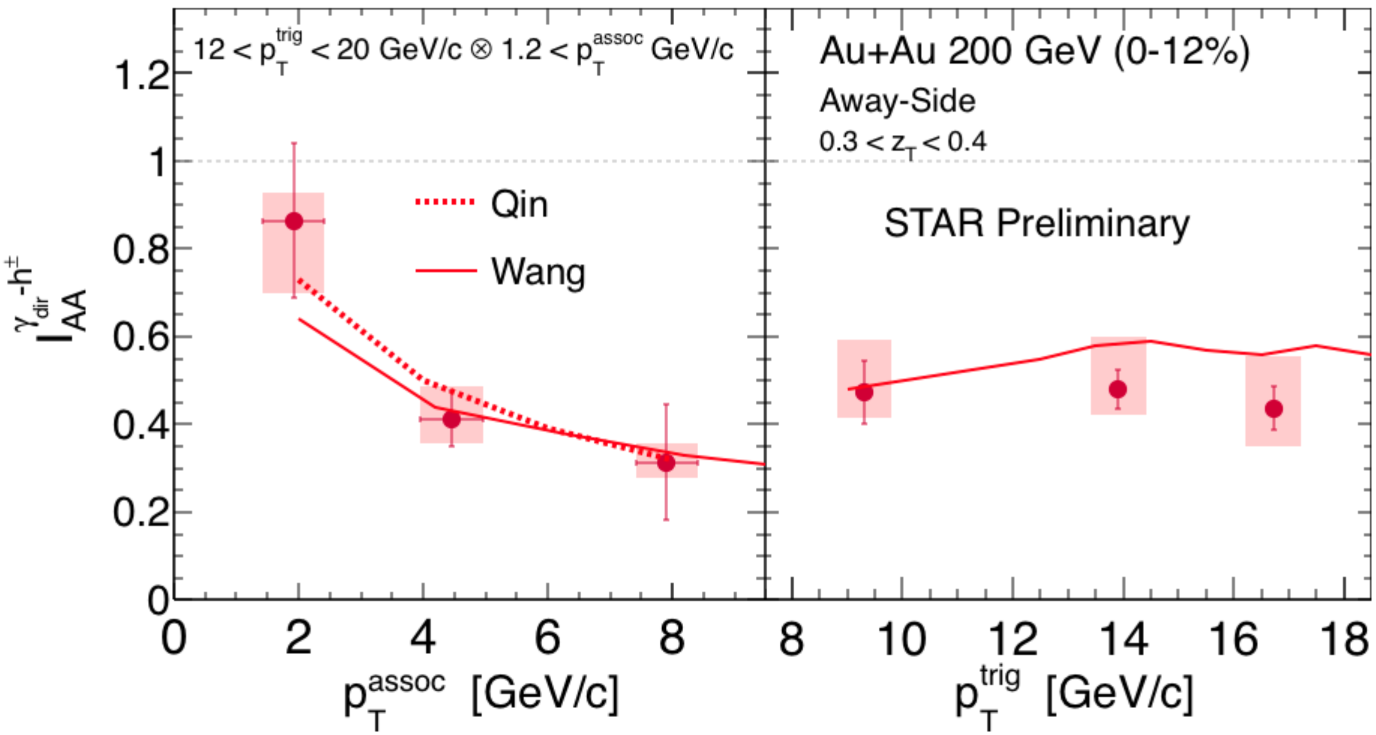
Nuclear modification factor: *Integration window dependence*

$$I_{AA} = \frac{D(z_T)_{AA}}{D(z_T)_{pp}}$$



- **These error bars are largely correlated, but within these uncertainties no significant dependence of suppression on integration window is observed both for γ_{dir}-h± and π^0-h± I_{AA} results at high p_T^{Trig} ($12 < p_T^{Trig} < 20$ GeV/c)**

Nuclear modification factor: *p_T^{assoc} and p_T^{Trig} dependence*



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$$I_{AA} = \frac{D(z_T)_{AA}}{D(z_T)_{pp}}$$

- ***Clear away-side p_T^{assoc} dependence of* suppression**
- **No direct photon trigger energy dependence of suppression at high-p_T**
- **Both the models explain the data well**

Summary

- γ_{dir}+hadron and π^0+hadron correlation study help to understand the effect of medium formation in AuAu comparison with pp collisions

- Transverse shower profile technique is used to discriminate between direct photon and neutral pion sample

- Away-side hadron of triggered dir. photon and π^0 show similar suppression, whereas at very low z_T suppression is less compared to high z_T

  - No direct photon trigger energy dependence of suppression is observed at high-p_T

  - $I_{AA}^{\pi0\text{-}h} < I_{AA}^{\gamma dir\text{-}h}$ isn't observed in $0.1 < z_T < 0.9$ range, within uncertainties

  - *Clear away-side p_T^{assoc} dependence of* suppression is observed for $I_{AA}^{\gamma dir\text{-}h}$

Back Up

Extraction of *associated Yields:* *Of γ_{dir} and π^0 trigger*

- Near-side and away-side yields are extracted within $|\Delta\phi| \leq 1.3$ and $|\Delta\phi - \pi| \leq 1.3$
- Extracted raw yields are corrected for charge particle reconstruction efficiency

- Extraction of γ_{dir} associated yields:
  Assuming near side γ_{dir} associated hadron yield is zero,

$$Y_{\gamma_{dir}+h} = \frac{Y^a_{\gamma_{rich}+h} - RY^a_{\pi^0+h}}{1-R}$$

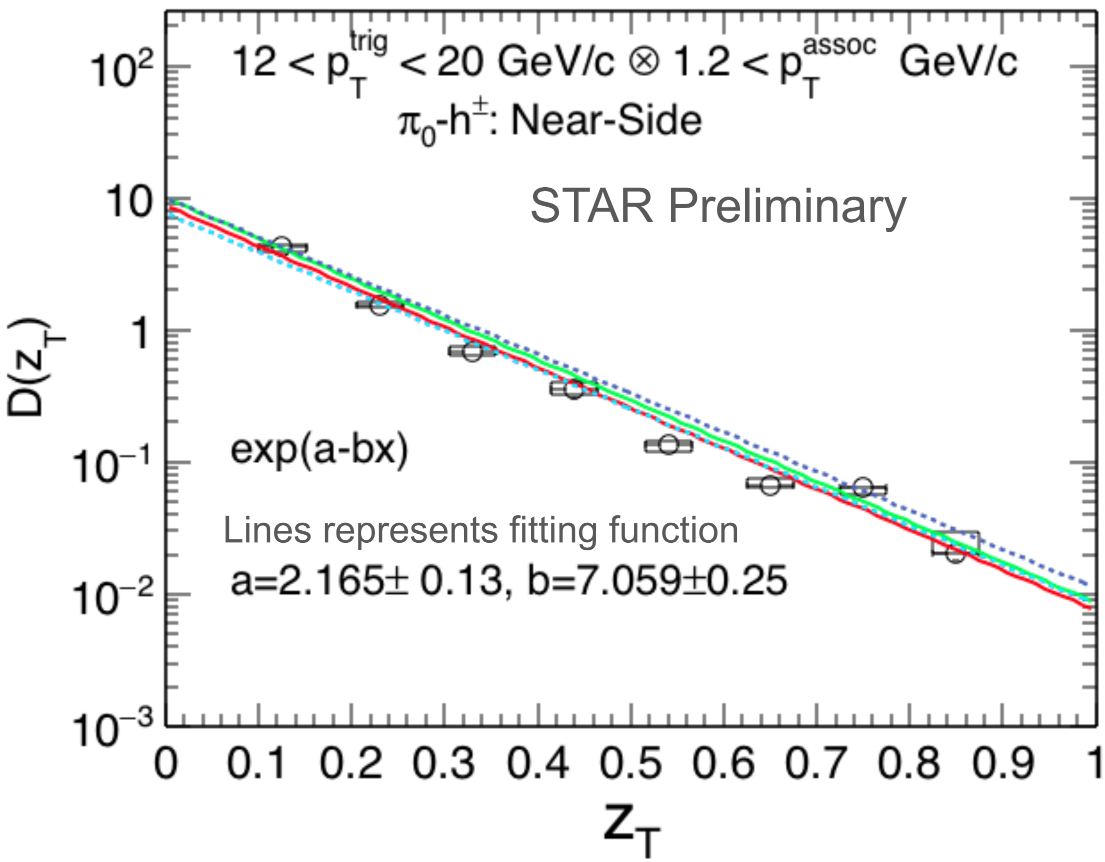
$$R = \frac{Y^n_{\gamma_{rich}+h}}{Y^n_{\pi^0+h}} \quad \text{and} \quad 1-R = \frac{N^{\gamma_{dir}}}{N^{\gamma_{rich}}}$$

$Y^{a(n)}_{\gamma_{rich}+h}$: away-side (near-side) yields of associated particles per γ_{rich} trigger

$Y^{a(n)}_{\pi^0+h}$: away-side (near-side) yields of associated particles per π^0 trigger

- The values of $(1-\mathcal{R})$ are found to be ~40% and ~70% for pp and AuAu central (0-10%) collisions, respectively

Contribution of π^0 energy over total jet energy

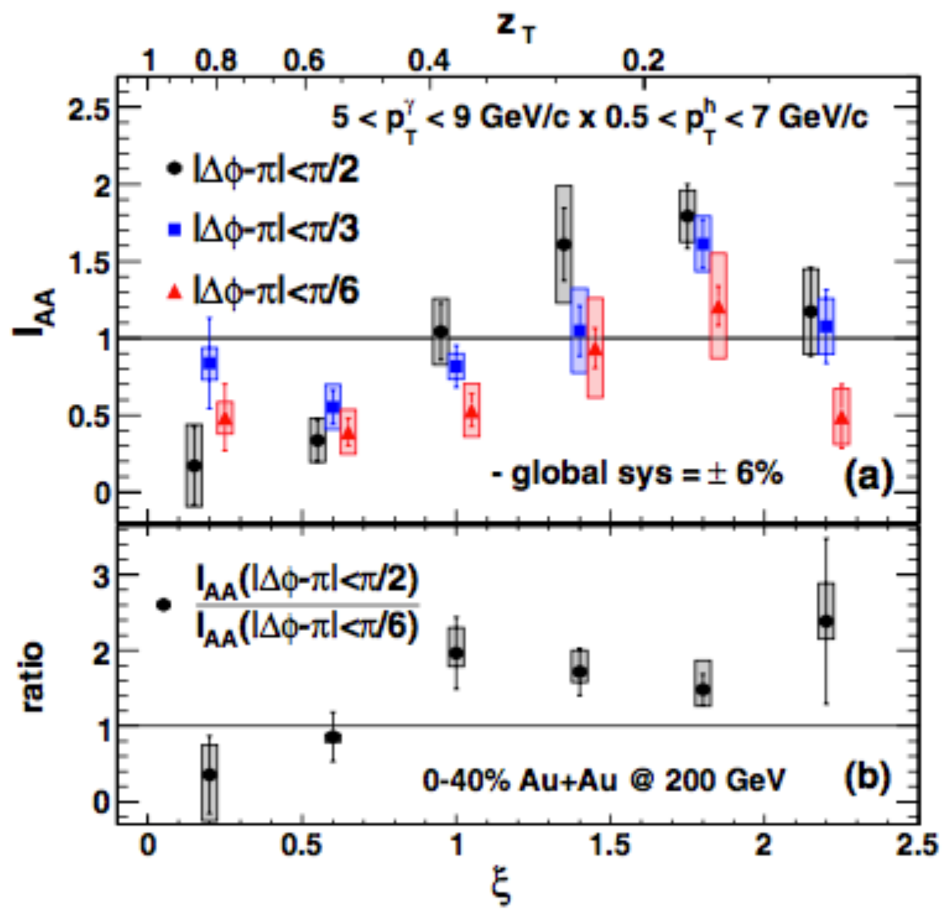


$$f(z_T) = e^{(a-bz_T)}$$

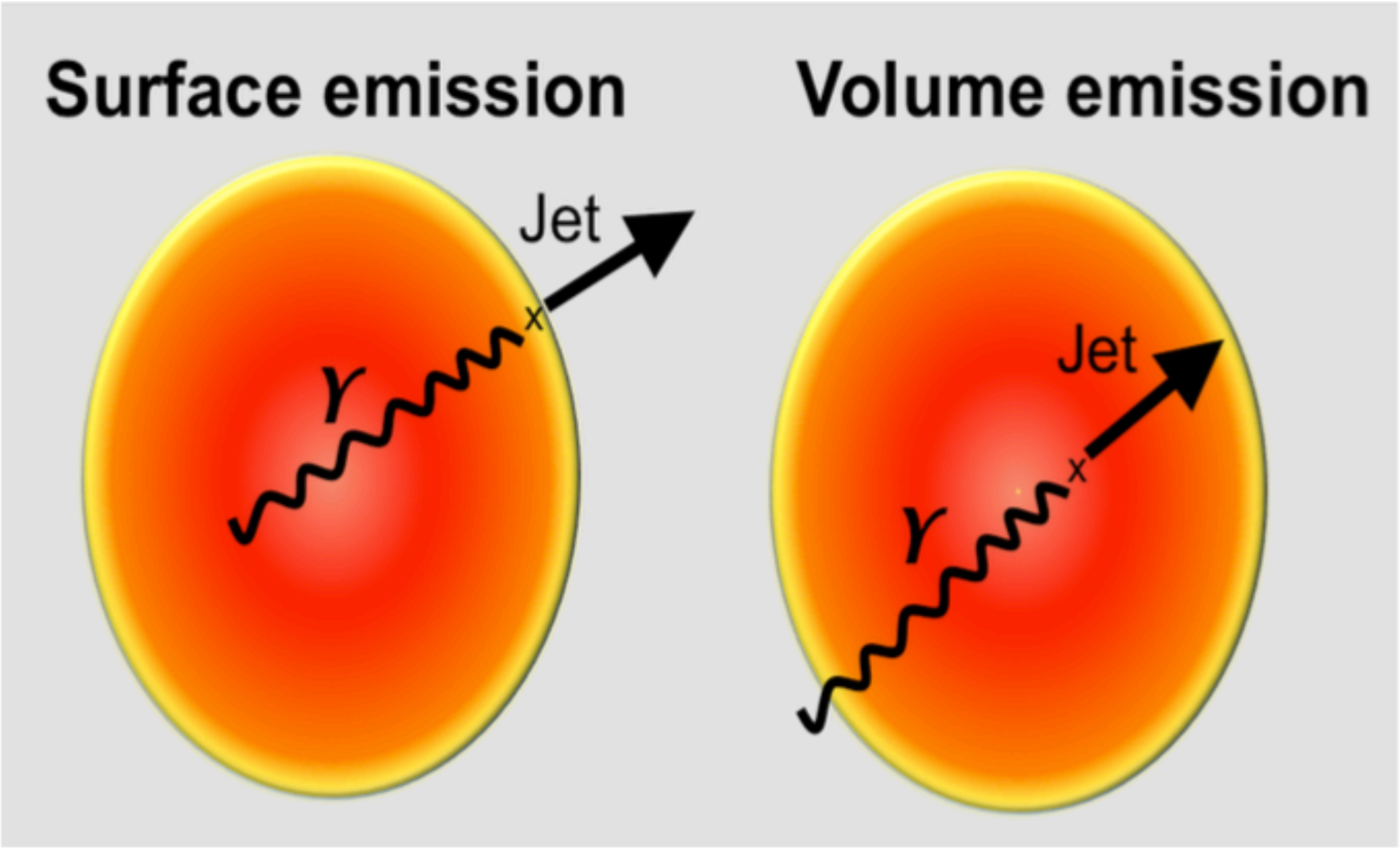
$$I = \int_0^1 z_T e^{(a-bz_T)} dz_T$$

$$frac.\ contribution = \frac{1}{1+I}$$

83%-88% fraction of energy carried by π^0 over total jet energy



- [PHENIX, PRL 111, 032301 (2013)]


Surface emission
Volume emission
Jet
γ
x
Jet
γ
x